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Impact detection and characterization in composite laminates with embedded fiber Bragg gratings

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Abstract

The use of composite materials has expanded significantly across civil, aerospace, and marine structures in both new designs and retrofits. The performance benefits from composites—typically, weight reduction with increased strength, corrosion resistance, and improved thermal and acoustic properties—are challenged by a host of failure modes whose genesis and progression aren't yet well understood. As such, structural health monitoring (SHM) plays a key role for in-situ assessment for the purposes of performance/operations optimization, maintenance planning, and overall life cycle cost reduction. In this work, arrays of fiber Bragg grating optical strain sensors are embedded into a pre-preg composite specimen that was designed by surrogate finite element model simulation, and will be subjected to both low-energy (non-damaging) impacts at various locations and high-energy damaging impacts at a known location. The impactor was designed along with the panel specimen for very specific energy levels, strain frequency, and strain amplitude response. Results from SHM algorithms developed via hypothesis testing are demonstrated on blind impact tests in order to determine the efficacy of embedded fiber Bragg grating arrays for assessing structural health of such composites.

Keywords: fiber Bragg gratings; impact detection; statistical model; composite laminates

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1. Introduction

Fiber reinforced polymer (FRP) composite structures are gaining more prevalence in the marine and aerospace industry due to their high specific strength and stiffness, corrosion resistance, and their ability to be molded into doubly curved, complex shapes [1-4]. The performance benefits from composites—typically, weight reduction with increased strength, reduced maintenance, and improved thermal and acoustic properties—are challenged by a host of failure modes (e.g., delamination, disbonding, fiber breakage, matrix cracking, and bearing damage in connections) whose initiation and progression are not yet as well understood as failure modes in comparable metallic materials. In addition, damage to FRP structures cannot always be determined by visual inspection.

Impact-induced delamination and/or fiber breakage are one important failure mode in marine and aerospace composite applications. In this paper, we consider the detection and localization of impact-induced delamination in a glass-epoxy composite specimen [5-10] where an array of fiber Bragg gratings (FBGs) were internally embedded inside the specimen at fabrication and used to measure strain response to calibrated impacts. The strain responses were mined for features from time domain (auto-regressive parameters) and frequency domain (power spectral density estimated peaks) to track the progression of delamination from repeated impacts. Statistical modelling and hypothesis testing was done to demonstrate probability of detection. A rigorous hypothesis test, invoking a statistical model of the Mahalanobis distance, is used for damage level decision-making validation.

2. Experimental testbed

A solid laminate uniform thickness prepreg panel was designed and fabricated for the proof of concept demonstration. The glass-epoxy prepreg used in the fabrication was Axiom AX-3201S/EL. The target thickness was 0.5” to represent a full thickness part that may be employed in fleet application. Small panels were fabricated in order to get an accurate cure ply thickness. The cured ply thickness was determined to be ~0.03”, resulting in a build-up of 16 plies to reach the 0.5” target thickness. During fabrication 40 FBG sensors from Alxenses were embedded in the panel. The sensors were placed on the first ply followed by the 15 additional plies. The locations of these sensors are identified in Figure 1. The panel was subsequently cured in accordance with the process provided by Axiom.

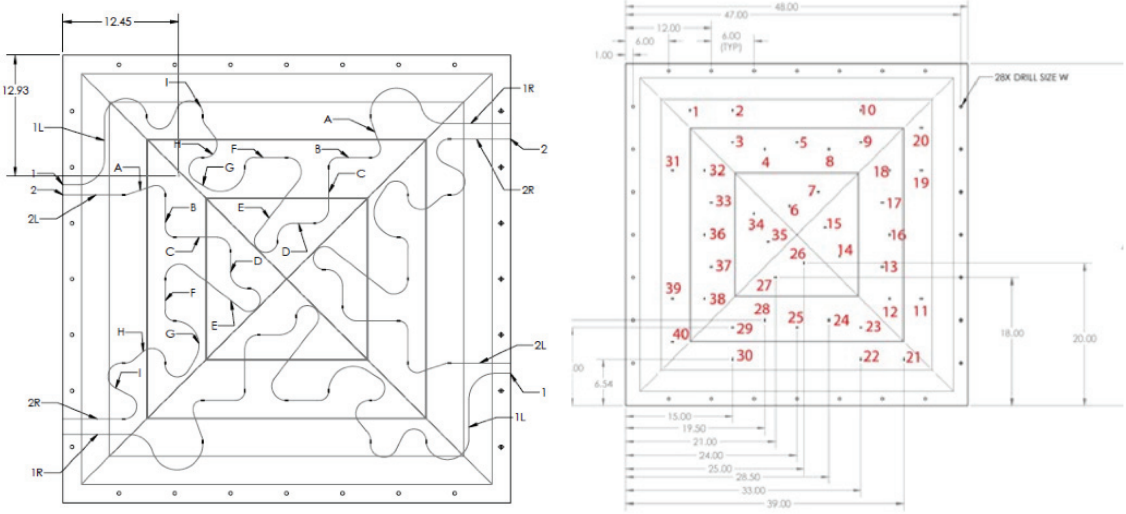

Figure 1 (left) location and numbering of FBGs and (right) FBG array path design.

The panel was mounted to an aluminum test frame using C-clamps, and a mechanical shaker was mounted on the backside of the panel to the frame (Figure 2). The impactor was attached to a pendulum that could be moved to